Ocean Optical Modeling: The Complex Optical Field Structure and Dynamics of Coastal Case 2 Waters

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LONG-TERM GOAL

Models and algorithms for ocean optical phenomena that are mechanistically-based are the overall goals for this project. From these considerations come models that are robust and reliable. A standard optical model for the oceans is in development. This is being done by parameterizing and incorporating the optics of the coastal ocean system into Case 1 optical models.

SCIENTIFIC OBJECTIVES

My efforts are directed toward the production of a valid, predictive Coastal Ocean Optical Model of Type 2 waters. The unmet need so far is the accounting for the effects of suspended and resuspended particulate minerogenic matter.

APPROACH

I have been applying open ocean paradigms as the basis for predictive models of the complex coastal ocean systems. We have available a standardized suite of known inherent optical properties, the Open Ocean Optical Model (Weidemann, et al, 1995). The new volume scattering functions of Stramski and Mobley (1997) are being investigated for their suitability in coastal ocean modeling and simulations. However, the critical information needed for coastal optical prediction and modeling is the mass concentration and size distribution of minerogenic particulates. When suitable information is available on the bottom sediments, as is the case for Oceanside, CA (Inman, 1953), Timothy R. Keen is able to predict mass and size distributions of resuspended minerogenics given further information about external forcing functions such as tides, wind stress, and waves. This comes from the sub-regional very high resolution model of Oceanside, California. Specifically, it is the semi-explicit, primitive equation Princeton Ocean Model (Oey and Chen, 1992). What has been accomplished recently is the increase in resolution of the Princeton Ocean Model (POM) to 900 m in the x-direction (60 grid points) and 600 m in the y-direction (113 grid points) so that individual stations in the Oceanside exercise can be modeled. The Inman (1953) report indicates that the sediments in this area are quartz sand and silt and the individual particles are thus approximately spherical. Thus, polydisperse Mie calculations give a volume scattering function and total scattering coefficient for the resuspended sediments. Thus we have a new approach to modeling the optical environment of the near shore region, the bottom up approach. This is to be contrasted with the top down approach, accounting for the optical effect of living cells intercepting the solar flux, typical of the open ocean. The bottom up approach, accounting for resuspension from the bottom, is of course complementary with the top down approach and absolutely necessary for modeling the optics of the coastal region. With this total suite of information on coastal

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inherent optical properties, I simulate the solution of the radiative transfer equation by Monte Carlo methods on the Cray T3E. Parallelization of the Monte Carlo simulations has increased their efficiency by orders of magnitude. This method easily accounts for the complicated non-linearities introduced by multiple scattering, internal radiant emission, and internal apparent radiance sources, i.e. reflective bottoms and wave-disturbed water/air interfaces. The optical energy trapping hypothesis and 3-parameter model (Stavn et al, 1984) provide the minimally acceptable description of the coastal ocean light field.

WORK COMPLETED

Detailed predictions of the minerogenic component of optical environment of Oceanside, CA for the field experiment of October 1995 have been completed. The increased resolution of the POM applied by Timothy R. Keen, Ocean Dynamics and Prediction Branch of the Naval Research Laboratory, Stennis Space Center, MS allowed the calculation of the minerogenic scattering coefficient for each station of the Oceanside, California field exercise. Detailed predictions for other field sites are currently underway.

RESULTS

With the increased resolution of the (POM), predictions for the mass and size distribution of resuspended quartz sand and silt were provided for each individual station in the Oceanside exercise rather than the average values utilized previously (Stavn et al, 1998). Significant resuspension was demonstrated for the near shore stations at 8 and 12 m depth. For 16 m stations the amount of resuspension due to combined wave-current shear stresses was small and little activity was detectable for the deeper stations. Significant resuspension for the deeper stations has been postulated from the action of internal waves. The capability of the high resolution model to account for internal waves will be investigated in the future. Among the results of the high resolution simulation are the transport of sediments from their area of origin shore ward. Rather fine sediments are reported as significant components of the suspended sediment of the near shore (8 m depth) stations. This transport gives both bimodal (2 and 50 μm diameters) and unimodal suspended sediment distributions (one at 73 μm and another at 107 μm) which directly contradict the usual hyperbolic or simple logarithmic assumption of the size distribution of suspended particles. This is to be expected for a high-energy near shore environment. For a wavelength of 532 nm and a real refractive index of 1.25 with no absorption in the particulates (reasonable assumptions for the particulates of Oceanside, CA on those dates), Mie calculations were performed on the size distributions of the particulates from all stations in the near shore region. A typical suite of calculations is given in Table 1 where $b_q(532)$ is the total scattering coefficient at 532 nm for suspended quartz sediment from the polydisperse Mie calculation, $b_a(532)$ is the total scattering coefficient determined from the (chlorophyll + pheophytin) concentration at station SCM2 from the open ocean model, and $b_T(532)$ is the total scattering coefficient recorded at station SCM2 with the AC-9 meter. The total scattering calculated for the suspended sediment and the organics (algae, organic detritus, etc) are summed in Table 1. This summation is a close approximation of the actually measured total scattering for the station on 25 October 1998. Estimates were possible outside the range of measured values, the AC-9 meter having been held about half a meter off the bottom.

Table 1. Station SCM2, Oceanside, CA. 25 October 1995

latitude   x longitude
33.2278   117.4206

$b_q(532)$ m^{-1}	$b_q(532)+b_a(532)$ m^{-1}	$\mathbf{b_T(532)}$ m^{-1}	Depth (m)
0.130	0.420		1.76
0.147	0.437	**0.527**	3.21
0.167	0.457	**0.557**	4.38
0.189	0.479	**0.535**	5.34
0.277	0.567	**0.616**	7.27
0.412	0.702	**0.874**	8.31
0.729	1.019	**0.857**	8.98
2.637	2.927		9.41

We see that the scattering due to resuspended quartz-like particulates can represent a significant percentage of the total scattering coefficient on up to the surface, perhaps 30%. Toward the bottom the suspended minerogenic matter becomes the dominant component of the hydrosol total scattering coefficient.

IMPACT/APPLICATION

These simulations with accurate estimates of minerogenic matter from coastal ocean current models provide the basis for a predictive near shore optical model. We have shown that good predictions can be made with the ocean current model and a chlorophyll-based model derived from the open ocean. The assessment of minerogenic matter near the surface will have strong implications for remote sensing of the coastal ocean. Both passive and active (expected return from a laser probe) remote sensing efforts will be improved. Underwater visibility studies will be improved from determinations of multiple scattering and multiple internal reflections from factoring in minerogenic particles validly.

TRANSITIONS

The results of our Type 2 simulations with minerogenic matter and the corresponding effects on backscattering are being utilized by Frank Hoge, NASA - Wallops Island, VA, for active remote sensing work in coastal regions. At the Naval Research Laboratory, Remote Sensing Branch, Stennis Space Center, Sonia Gallegos is interested in applying these results to remote-sensing algorithms of the Yellow Sea as does Rick Gould of the same group for high minerogenic coastal remote sensing algorithms.

RELATED PROJECTS

Herewith I list the projects being pursued concurrently with the Littoral Optical Environment initiative of the Naval Research Laboratory and the Office of Naval Research.

1 - Timothy R. Keen, Ocean Dynamics and Prediction Branch (Code 7322), Naval Research
        Laboratory, Stennis Space Center, MS is working closely with me to provide very high

resolution results for a given latitude and longitude for mass, size distribution, and type of resuspended minerogenic material from the Princeton Ocean Model. This is being done through the Very High Resolution 4-D Coastal Ocean Currents Program element 62435N of ONR.

2 - Douglas Neilsen, Coupled Dynamic Processes Section (Code 7331), Ocean Sciences Branch (Code 7330), Naval Research Laboratory, Stennis Space Center, MS has been interested in the optimal wavebands to utilize in a surface layer model of hydrodynamically forced primary productivity in the Arabian Sea. We have been considering models of absorbing and scattering conditions of the major types of suspended cells. These resolve into large cell and small cell models.

3 - Vladimir I. Haltrin, Coupled Dynamic Processes Section (Code 7331), Ocean Sciences Branch (Code 7330), Naval Research Laboratory, Stennis Space Center, MS has been working with me on optimized codes for Mie Scattering calculations and on scattering properties of small clay particulates.

4 - Dariusz Stramski, Marine Physical Laboratory, Scripps Institution of Oceanography, UCSD, La Jolla, CA has a database of optical properties of living and organic suspended particles (Stramski and Mobley, 1997). We will be using this database in various radiative transfer simulations. The more interesting results will be jointly published.

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